Suspended Sediment Flexes in a Tropical Estuary, West Coast of India

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Abstract

Annual transport processes of suspended sediments in Beypore estuary a tropical estuary along the south west coast of India- were investigated based on time series measurements within the system It's observed that the sediment transport was upstream dining the premonsoon period and downstream during othei seasons. Correlation between concentration and velocity at tidal frequencies established that the upstream movement of sediment was largely accomplished by tidal pumping. Maximum flux of the suspended sediment was obtained (1220.97 mg. cm $^{2}s^{-1}$at the river mouth, during the monsoon period . High negative fluxes were obtained during premonsoon penod (381.31 mg. $cm^{-2}s^{-1}$) at the mouth of the estuary. During the months of low river flow, the estuary received net sediment inputs from the continental shelf and during high (lows exported sediments to the continental shelf depending on the magnitudes of the floods The major input of sediment from the watershed was 8.8 x 10^4 tons. yr^{-1} and the net sediment transported towards the continental shelf was estimated as 5.7 x 10^4 tons y^{-1} .The net trapping of sediment in the lower estuary was approximately 3.1 x 10^4 tons.yr^{-1} .It's confirmed that the estuary has a pronounced turbidity maximum zone at the bar mouth, where rapid short term deposition of sediments occur during and following the monsoon freshet.

Keywords

Tropical estuary, sediment budget, Turbidity Maximum Zone, India

Introduction

Tropical estuaries offer an excellent opportunity to study the sediment processes in an environment influenced by riverine and marine factors, including sediment input from rivers, mixing of fresh and salt waters under the influence of tides and the prevalent dry and wet seasons. The transport and trapping of sediments are controlled by tidal dynamics, river discharge and particle dynamics throughout the estuarine system. Sediment budget is a quantitative inventory of all the sediment inputs, outputs and storage within the system. Estuarine processes control the distnbution and transportation of suspended sediments. These processes vary in a systematic manner within tidal and weather cycles. During a periodic event many estuaries can carry high-suspended sediment loads and this can drastically change the pattern of sediment transport and dispersion in the system (Nichols, 1977; Perez et al. 2000). The increased suspended sediment into the estuarine ecosystem is causing enormous economic burden by the way of the infrastructures for navigation and flood mitigations (Eyre et al. 1998).

It is therefore necessary to study the processes governing the sediment movement in order to understand contemporary problems in estuarine environment such as reclamation, harbour development and dispersal of pollutants (with an affinity of fine, cohesive sediments) and urbanisation (Van Leussen and Dronkers 1988; Eyre et al. 1998; Wu and Shen 1999). Increased suspended sediment into the estuarine ecosystem is causing enormous economic burden to the society, which necessitate maintaining the water quality and removal of sediment for navigation and flood mitigation purposes.

In view of the above, site specific research on seasonal variability of suspended sediments is needed to understand the variability with an application to the future development projects. This paper investigates the Beypore estuary, a tropical estuary along the south west coast of India, by evaluating the characteristics of flushing and variations of suspended sediment transport mechanisms as well as the entrapment of sediment under varied flow conditions.

Environmental Setting

The third largest west flowing rivers in Kerala, the river Chalryar originates in the Illambagiri hills (Western Ghats) at an elevation of about 2100 above MSL and follows a narrow and meandering course along its length of over 170 km before joining the Arabian sea at Beypore (Lat.ll^0 58', Long.75° 50'E). A medium port (Beypore port) exists at the river mouth and recent development plans envisage transforming it to an all weather port on Build Operate Transfer (BOT) basis - the first of its kind in the region. Since time immemorial, the system has played a major role in the socio-economic and cultural history of Kerala..The Beypore port was one of the prominent ports and fishing harbours of ancient Kerala and an important trade and maritime centre - much sought after by the merchants of western Asia for it's ship building industry. The estuarine habitat plays an important role in completing the life cycle of many of the commercially important prawns. Major industries of the region include coir retting and fish processing units. In addition to these and with various agricultural activities, the narrow coastal zone also accommodates several important residential locations

There exits a rock outcrop on the south side of the river outlet extending for a few hundred meters towards the south .The coast just behind the outcrop is protected and the coastline recedes behind these outcrops Seabed is flat off Beypore, with a slope of approximately 1 in 400. The seabed material is primarily silty loam and the inner harbour consists of coarse sand with no traces of silt and clay .Climate of the region is governed by the monsoon and the rainfall averages to 300 cm. yr^{-1} .Tides in the region are of semi-diurnal type and tidal excursion was noticed upto 15 km upstream. Earlier studies of the estuary included investigations on the exchange of fresh and salt water circulation and mixing and distribution of vertical suspended sediments (Hossain et al. 1987; Nair, 1987). However, these studies were mostly confined to the lower reaches .The present study was initiated to understand the flux of suspended sediment in the inner estuarine zones as well as the sediment budget of the estuary.

Materials and Methods

In order to study the suspended sediment distribution in the estuary, it has been divided into four sections at 5 km intervals up to 15 km upstream with two

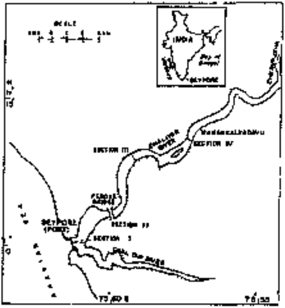


Fig. 1. *Observation sections and stations in the estuary*

transverse stations on each section. A map showing the sampling locations is given in Fig. 1. The tides at Beypore estuarine system are of semidiurnal type with a period of 12hr and 40 minutes. The maximum tidal range obtained during spring tide in the entire period of study was 1.2m and during neap tide it was 0.80m. The water level data during the period of study was collected from Minor Port Authorities, Beypore. Monthly data on current, salinity and suspended sediment were collected for one tidal cycle (13hrs) from four sections for a period of nearly one year from October 1990 to September 1991(Fig.l). Hourly measurements of current and salinity at lm-depth interval at each station were made using the Direct Reading Current Meter (accuracy for velocity + lcm. s 'and direction ± 2.68°) and STD meter (accuracy + 0.1 x 10^{-3}) respectively. Suspended load were measured at the surface, mid depth and bottom. The water samples were filtered through a pre-weighed Millipore filter paper of 0.45mm pore size and a diameter of 47 mm. After filtration the filters were rinsed with distilled water thrice and dried at 60°C. The difference between final and initial weights gives the concentration of the suspended sediment in mg. 1^{-1} (Yarbo et al. 1983). The filtered samples were used for grain size determination. Percentage of sand, silt and clay portions was determined by sieving through a net of 64 m mesh size and pipette analysis (Krumbein and Pettijohn, 1938).

Flushing characteristics

Flushing times were calculated using the fraction of freshwater method (Kennish, 1986). The estuary was divided into three boxes by echo sounding profiles (cross sections) of approximately 5000 m intervals based on the homogeneity of the system. The average salinity in each box was calculated from vertical salinity profiles and lateral salinity variations. Box volumes were calculated by multiplying the average of the two bounding cross-sections at high tide by the axial distance between them.

If S is the salinity of the mixed water and Ss is the salinity of the seawater, then the freshwater fraction (f) is calculated from

$$f = (Ss-S)/Ss$$

The flushing time (T) is computed as

$$T= (Mean\ (f).V)/R$$

V is the total volume of the estuarine regions, f is the freshwater fraction and R is the river discharge.

Sediment Flux

Suspended sediment, fluxes were calculated from velocity and sediment concentration (Stern et al. 1986; Stern et al. 1991). The sampling was done at two stations in a cross section and at three depths (surface, mid depth and bottom) at each station. The cross sectional and depth averaged value of the horizontal component of the velocity vector at each section during every sampling hour in the semi-diurnal observation was computed and then multiplied by the respective cross sectional and depth averaged value of the suspended sediment concentration for the water column to get the instantaneous flux. The net fluxes were calculated by dividing the algebraic sum of the instantaneous fluxes over a tidal cycle by the number of observations in the tidal cycle .Net fluxes for all the four cross sections were calculated. Material transport through a particular cross section was obtained by multiplying the net fluxes by the mean cross sectional area. The positive sign indicated transport towards the sea and the negative sign indicated tiansport towards the river.

River Input

River flow data during the period of study was obtained from Central Water Commission, Cochin, Kerala. The yearly suspended sediment input from the Chaliyar river into the estuary was computed from the daily discharge data available for the region .For computation of the nvei input of suspended sediment, river discharge data and mean suspended sediment concentration during ebb tide at the upper most section (nearly the upper limit of the tidal influence) are used.

Results

Flushing time scale

Flushing time was calculated for every month and is given in Fig .2, which showed higher values during the pre monsoon season and lower values during monsoon After the post monsoon season, the values increased from

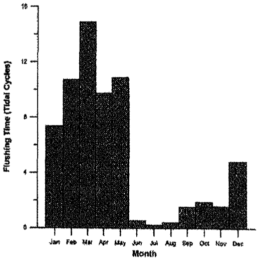


Fig 2 *Flushing characteristics*

January onwards and maximum value was found to occur in March (14.85 tidal cycles), which shows that pollutants can't be flushed out easily from the estuary during this period. During monsoon months, the river discharge was high and the time required to flush out the materials present in the estuary was very less. In July, the value of flushing time required to flush out the materials present in the estuary was very less. In July the value of flushing time was found to be 0.23 tidal cycles. Higher values were not observed dunng the post-monsoon period. Flushing time computed in October was 1.89 tidal cycle. During November and December the flushing time values were 1.6 and 4.81 tidal cycles respectively.

From the results obtained, it can be suggested that a pollutant introduced in the estuary will not be flushed out easily during the pre-monsoon season because the buoyancy of the incoming freshwater was insufficient to overcome the mixing due to strong tidal currents. But during the monsoon months domestic and industrial wastes discharged into the estuarine system will be flushed out easily due to high river run-off.

Semi diurnal and seasonal variation of suspended sediment concentration

During post-monsoon the maximum value of the suspended sediment concentration was obtained at the river mouth during flood tide. It varied

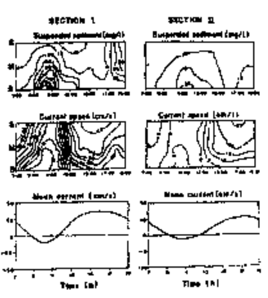


Fig.3(a) *Semi diurnal variations of suspended sediment concentration during postmonsoon season at section - I and section - II (S - surface, M - mid depth and B - bottom)* between 15 mg. 1^{-1} to 55 mg 1^{-1} from surface to bottom at the peak Hood period (Section I, Fig 3a) where the upstream current velocity was 10 cm.s^{-1} .A surface related higher concentration of suspended sediment 30 mg .1^{-1} at the liver mouth was found during this period due to the comparatively higher aver discharge. At 5km upstream from the river mouth the suspended sediment concentration varied between 10 mg.l^{-1} to 20 mg. 1^{-1} from surface to bottom (Section II,

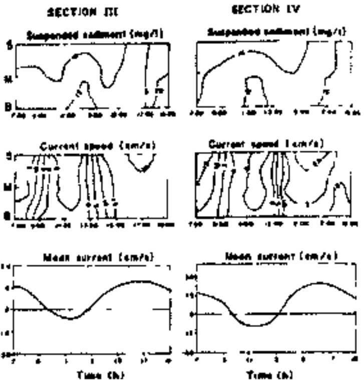


Fig. 3(b) *Semi diurnal variation, of suspended sediment concentration during, postmonsoon season at section - I and section - II (S - surface, M - mid depth and B - bottom)*

Fig .3a) The suspended load during the peak flood period varied only between 10 mg .1^{-1} to 15 mg.1^{-1} from surface to bottom at the upper reaches of the estuary (Fig .3b).

The concentration of suspended sediment during this season was maximum at the peak flood period, due to the suspension of sediments created by the strong currents at the lower reaches of the estuary

Higher tidal influx was observed during the pre monsoon period .The estuary was well mixed due to high intrusion of saline water The strong currents produce high suspension of clay and silt materials present in the lower

Table -1 : Texture of sediments during different seasons

SECTIONS	TEXTURE(%)		
	SAND	SILT	CLAY
		POSTMONSOON	
Section I	72 75	17 55	10 20
Section II	78 95	16 25	4 80
Section III	95 60	3 85	0 55
Section IV	94 45	4 75	0 80
		PREMONSOON	
Section I	64 80	22 30	12 90
Section II	66 30	20 60	13 20
Section III	92 50	6 00	1 50
Section IV	90 40	7 45	2 15
		MONSOON	
Section I	71 45	26 20	2 35
Section II	70 10	28 40	1 50
Section III	99 70	0 30	0 00
Section IV	99 50	0 50	0 00

reaches of the estuary (Table- 1) Sediment concentration in the water column varied between 40 mg .1 to 60 mg . 1^{-1} from surface to bottom during flood tide at the river mouth (section - I Fig. 4a). The variation was more predominant at the lower reaches of the estuary. The bottom related maxima of the suspended sediment was due to the suspension of the bed sediments by strong tidal currents. At section II (Fig .4a) the variation of suspended sediment concentration was from 25 mg $.1^{-1}$ to 45 mg $.1^{-1}$ from surface to bottom .Fig. 4b shows that at the upper reaches of the estuary the suspended sediment concentration varied

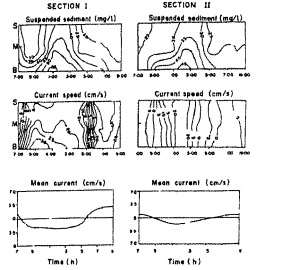


Fig.4(a). *Semi diurnal variation of suspended sediment concentration during postmonsoon season at section - III and section - IV*

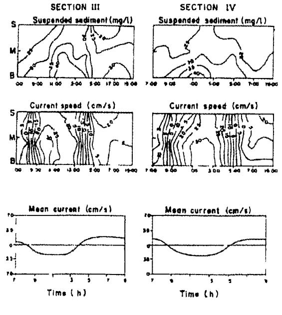


Fig. 4(b). *Semi diurnal variations of suspended sediment concentration during postmonsoon season at section -III and section - IV* between 25 mg.l^{-1} to 40 mg.l^{-1}. The high values of upstream currents and suspended sediment concentration were observed during this season particularly in the lower reaches of the estuary.

River discharge was maximum during the monsoon season and most of the suspended sediment present during this month was mainly carried by the river discharge and the entire estuary was found to be the river dominated and a surface related maximum value was observed due to the strong freshwater discharge. High sediment concentration observed in the entire estuary was mainly due to the strong river runoff. A surface related maximum value of 100 mg .l^{-1} was obtained at section-I (Fig. 5) may be due to the sediment carried by

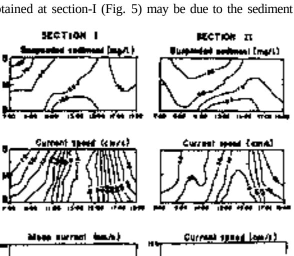


Fig.5. *Semi diurnal variations of suspended sediment concentration during premonsoon season at section - / and section - II*

the river run off. The higher value of the bottom sediment concentration (100 mg.l^{-1}) was observed during the flood tide. During this season, the seaward transport dominates the upstream transport.

Turbidity Maximum Zone

Turbidity maximum zone of estuaries is a distinct factor characterised by the maximum suspended load concentration. From Table 1, it has been found that sediments of sections 1 and 2 contain more silt and clay percentage hence these sections are capable of getting more suspended load compared to section

3 and 4, which are composed of 90 to 99 *%* sand. Thus the lower part of the estuary is having more turbidity maximum zone, especially during pre-monsoon seasons. In the pre-monsoon months, it was seen in the lower reaches of the estuary because the suspended sediment concentration was higher in the lower sections due to the presence of silt and clay materials in these sections.

Sediment flux

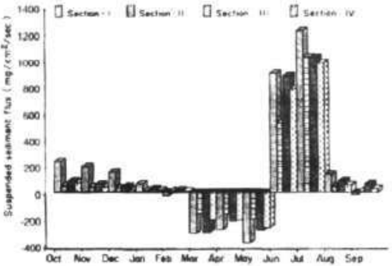
The net flux of suspended ($mg.cm^{-2}Isec^{-1}$) through four cross sections in the estuary represented in Fig 6. Generally the flux increases from head to mouth of the estuary. Owing to the high river discharge and associated seaward current, large positive fluxes (toward the sea) were observed during monsoon.. The maximum flux of the suspended sediment is obtained during July (1220.97 $mg .cm^{-2} .s^{-1}$) at the lower most section of the estuary. During the post monsoon season, fluxes were positive but lower in values as compared to monsoon months. Sediment fluxes were upstream during premonsoon period with a maximum value in May (-381.31 $mg.cm^{-2} .s^{-1}$) at river mouth.

Suspended solid concentrations and transports are high during peak monsoon period. The annual sediment input estimated during the study period was 8.8×10^4 $tons.yr^{-1}$. The net sediment transported towards the sea was estimated to be $5.7 x l0^4$ $tons.yr^{-1}$.

The annual entrapment of sediment in the estuary was obtained by taking the difference between the total river input and net seaward transport. As a result the estuary is a sink for the suspended sediment. The annual entrapment of the sediment in Beypore estuary was calculated to be $3.1 x l0^4$ $tons.yr^{-1}$.

Discussion

One of the sources of estuarine sediments is from the continental shelf (Biggs, 1970; Bokuniewicz et al. 1976; Verlaan et al. 1997; Guan et al, 1998; Verlaan and Spanhoff, 2000; Hossain et al. 2001) and sometimes this marine input may dominate the sediment supply in the system. In the Beypore estuary, a similar situation was observed during the period of observation during pre-monsoon with a net input of suspended sediment from the adjacent Arabian Sea. A possible explanation for the net input of suspended sediment is the successive increase of the ebb tide level during the spring neap cycle, which induces a residual accumulation of water in the estuary. During the neap-spring cycle (with decreasing storage of water in the system) the net escape of suspended sediment from the estuary is less than the net input of sediments during the spring neap cycle, which may be due to the trapping of sediments in the adjacent zones, which are unable to resuspend and transport these materials during the spring neap cycle. This mechanism occurring during the fortnightly tidal cycles thus causes net sedimentation in the system during the lower discharges.



Semi diurnal variations of suspended sediment concentration during premonsoon season at section III and section IV

Estuarine sediment transport patterns can change during flood events (Nichols 1977 Robertson et al 1998 Fettweis 1998 Algan et al 1999) due to the large volume of freshwater input which allows sediment to escape seaward Though it was not possible to assess the impact of a major flood during the study penod the responses during moderate floods can be assessed based on the results of the flushing time scales (Fig 2) It s established that the estuary got completely flushed out during the penod of peak freshwater discharge Factors that cause a complete and continuous flushing of the estuary from upstream to the mouth is that the floodwater overcame the tidal push and the velocity of the flood water increased towards the estuary mouth These results thus imply that due to the small holding capacity the estuary could be subjected to significant morphological changes for any high flow events

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